A LIQUID PUMP

BACKGROUND OF THE INVENTION

This invention relates to a liquid pump used in the field where a small amount of liquid feed is required, for example feed of a sample to a tip of liquid chromatography or a chemical reaction microsystem (a micro total analysis system) and feed of a reagent to a 96-well plate

For a small amount of liquid feed, a manually-operated micropipette has been used for a long time. Automation of the operation of a micropipette has been achieved by using an automatic dispenser. A micro-dispenser has been used for the dispensing operation to a 96-well plate which stores many samples, and successive liquid feed in the micro-dispenser has been conducted by a cylinder-type liquid pump. In addition, some liquid pumps which have been widely used for liquid chromatography make use of a reciprocating motion of a plunger or a cylinder.

The foregoing widely used liquid pumps require a mechanical driving means using a motor and a cam. Furthermore, precise machining of the plunger for securing airtightness, selection of members which stand against frictional heat generated between the plunger and the tubular wall housing the plunger, desigining of valves suitable for continuous liquid feed, and collecting liquid for prevention of pulsating flow are also required.

Therefore, another liquid pump having bellows as a driving means instead of having the conventional mechanical driving means including the motor and the cam has been developed. This liquid pump is driven by a motion of the bellows caused by thermal expansion/contraction of liquid retained in the bellows. In particular, as shown in Fig. 6, this liquid pump includes a liquid container 21 hermetically retaining expandable-contractible liquid 25 in the hollow space thereof, a driving means 22 linearly reciprocating in response to the thermal expansion or contraction of the retained liquid, a pumping means 24 drawing or discharging the liquid by the reciprocating motion of the driving means 22, and a heating-cooling means 23 alternately heating and cooling the liquid container 21. The driving means 22 includes the accordion-shaped bellows communicating with the liquid container 21, and the pumping means 24 includes a cylinder 27 and a plunger 28 reciprocating in the cylinder 27. (Published Japanese Patent Application No. 2002-371955, Page 2, Fig. 1)

Moreover, there has been another liquid pump of this type that is driven by elastic membranes functioning as valves without using the reciprocating motion of the plunger and the cylinder. As shown in Fig. 7, this liquid pump has a tubular space (flow channel) for liquid feed and elastic membranes 31 forming part of an inner-wall of the space. Three or more of the membranes are placed in succession, and each of them is flexibly expandable-contractible by external stimulation. When the membranes 31 are extended in the space, they touch the facing portions of the inner-wall of the space, so that they block the space and form chambers 32.

In Fig. 7, (a) – (f) show a correlation between the membranes 31 and the liquid flow in sequence, and arrows 1 – 4 show a direction of motion of each membrane . As shown in Fig. 7, by extending the membranes 31 to form the chambers 32 in order, a small amount of liquid flows through the space from one of the ends to the other end. (Published Japanese Patent Application No. 2002-311007, Page 2, Fig. 2)

In addition, another proposed liquid pump of this type is a diaphram pump driven by static electricity. This pump supplies liquid by transforming a diaphram thereof. In particular, the liquid pump, as shown in Fig. 8, includes a chamber 41 having an inlet and an outlet for liquid feed, a first flow-resisting means 42 at the inlet side of the chamber 41, and a second flow-resisting means 43 at the outlet side of the chamber 41. The liquid pump further has a transformable diaphram 44 composing at least one side of the chamber 41, and a driving means for transforming the diaphram 44. By transforming the diaphram 44, the liquid pump draws liquid into the chamber 41 from the inlet side and discharges the liquid from the outlet side. The driving means has a fixed electrode 45 insulated electrically, a movable electrode 46 and a pressurizing element 47 provided on the movable electrode 46. When electric power is supplied between the fixed electrode 45 and the movable electrode 46, the pressurizing element 47 transforms the diaphram 44 to compress the chamber so that the liquid in the chamber flows out. (Published Japanese Patent Application No. 11-82309, Page 2, Fig. 1)

However, there has been a problem that the above-described conventional liquid pumps having the mechanical driving means for reciprocating motion of the plunger in the cylinder that they are expensive because the mechanical driving means requires precise machining.

There has been a further problem with these liquid pumps that the mechanical driving means and the cylinder generate unwanted noise. The noise generated by these liquid pumps when being installed in a medical device could be physiological burdens to patients and hindrances to medical practice. A liquid pump that does not generate such unwanted noise is desired not only in the medical field, but also in the acoustic field where extra attention not to cause unwanted noise is strongly demanded.

Additionally, there has been a problem with the above-described conventional liquid pump having the bellows as a driving means that a coefficient of thermal expansion of the liquid retained in the bellows is so small, and a large amount of liquid is required to obtain sufficient driving force; thereby a size of the liquid pump necessarily becomes big.

Furthermore, there has been a problem with the above-described conventional liquid pump having the elastic membranes functioning as valves, in which three or more of the elastic membranes placed in succession supply liquid, has complicated mechanism, and it is inferior in durability because the membranes are liable to deteriorate.

Finally, there has been a problem with any of the above-described

conventional liquid pumps that they have difficulty in performing a microvolume flow by the microliter or the nanoliter because of generation of heat in the mechanical driving means and/or generation of pulsating flow.

Hence, an object of the present invention is to solve the above-mentioned conventional problems and to provide a liquid pump having a very simple and downsized structure with the smaller number of necessary components which provides superior cost performance and operates without generating unwanted noise. Another object of the present invention is not only to control the liquid flow but also to facilitate the feed of extremely small amount of liquid by the microliter or even by the nanoliter.

SUMMARY OF THE INVENTION

A liquid pump according to the present invention has a pressure vessel with end-openings for hermetically holding liquid therein. The liquid flows from one of the end-openings to the other end-opening by utilizing a difference in a coefficient of thermal expansion of the pressure vessel and the liquid caused by heating or cooling the pressure vessel and the liquid together.

The liquid pump may further comprise a heating-cooling bath for receiving the pressure vessel, and the pressure vessel may have sufficient heat conductibility, so that pressure vessel and the liquid hermetically held in the vessel may be heated or cooled together by placing the pressure vessel in the heating-cooling bath.

The pressure vessel may generate heat by voltage, so that the heating may be conducted by applying voltage to the pressure vessel.

Furthermore, the pressure vessel may be a tube having an inner diameter of about 0.5 mm or less and a length of about 10 m or more.

Additionally, the heating-cooling bath may be either an air bath or a liquid bath.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Fig. 1 is a partially sectional view of a liquid pump according to an embodiment of the present invention;

Fig. 2 is a partially sectional view of a liquid pump according to another embodiment of the present invention;

Fig. 3 is a diagram of the liquid pump shown in Fig. 1 provided with a pressure indicator;

Fig. 4 is a diagram of a device for liquid chromatography using the liquid pump shown in Fig. 1;

Fig. 5 is a diagram of a device for liquid chromatography using the liquid pump shown in Fig. 2;

Fig. 6 is a sectional view of an example of a conventional liquid pump;

Fig. 7 is a sectional view of another example of a conventional liquid pump;

Fig. 8 is a sectional view of a further example of a conventional liquid pump.

DETAILED DESCRIPTION OF THE INVENTION

A liquid pump of the present invention, as shown in Figs. 1 and 2, hermetically holds liquid (not shown) in a pressure vessel 1 which is provided with end-openings 1a and 1b. The liquid pump feeds the liquid from one of the end-openings 1a and 1b by using the difference in coefficient of thermal expansion between the pressure vessel 1 and the liquid, which is generated by heating or cooling the pressure vessel and the liquid together.

In particular, when the pressure vessel 1 and the liquid hermetically held in the pressure vessel 1 are heated or cooled together, pressure is generated in the pressure vessel 1 by the thermal expansion of the liquid, and therefore the liquid flows into or out of the end-openings 1a and 1b by the difference of the pressure. In the case that the coefficient of thermal expansion of the liquid is higher than that of the pressure vessel 1, the inside of the pressure vessel 1 is pressurized in response to heating so that the liquid is discharged from the end-opening 1b. The liquid is drawn into the pressure vessel 1 through the end-opening 1a in response to depressurization of the vessel 1 caused by natural cooling after heating is stopped or caused by forced cooling with a cooler.

To keep the liquid hermetically held in the pressure vessel 1, the end-openings 1a and 1b are sealed with the plugs 2 and 2.

The pressure vessel 1 is preferably a long tube, so a metal tube, a synthetic resin tube or the like may be used. The pressure vessel 1 is also preferably made of materials having sufficient heat conductance. A metal tube is generally superior in heat conductibility to a synthetic resin tube, so it does not make much difference what a kind of metal is selected. However, when a synthetic resin tube is used, a selection of a kind of a synthetic resin tube is important because the heat conductibility tends to vary depending on the kind of a synthetic resin tube. A stainless tube, an iron tube, a copper tube, a brass tube, a titanium tube, or the like may be used as a metal tube. A polyethylene tube, a vinyl chloride resin tube, a nylon tube, a fluororesin tube or the like may be used as a synthetic resin tube. Above all, a polyethylene tube is preferable because of its excellent heat conductibility. Meanwhile, the coefficient of thermal expansion of the pressure vessel 1 depends on a combination with the liquid hermetically held in the pressure vessel 1, and therefore it does not make much difference whether the coefficient of thermal expansion of the pressure vessel 1 itself is high or low. When a metal tube is used as the pressure vessel 1, the coefficient of thermal expansion of the metal tube could not be higher than that of the liquid. On the other hand, when a synthetic resin tube is used as the pressure vessel 1, the coefficient of thermal expansion of the synthetic resin tube could be higher than that of liquid. Therefore, whether to use a metal tube or a synthetic resin tube as the pressure vessel 1 depends on whether the pressure vessel 1 and the liquid hermetically held

in the pressure vessel 1 are heated or cooled as well as the flow direction of the liquid (whether to feed the liquid in or out through either the end-opening 1a or the end-opening 1b).

The pressure vessel 1 of a tube having an extremely small inner diameter, namely an extremely narrow flow channel, and an extremely great length facilitates feed of the liquid in a very small amount by the nanoliter or the microliter. In the pressure vessel 1 shown in drawings, an extremely small amount of the liquid flow by the nanoliter or the microliter is achieved by using a tube having an inner diameter of about 0.5 mm or less and a length of about 10 m or more as the pressure vessel 1.

When the pressure vessel 1 having sufficient heat conductibility is used, the pressure vessel 1 and the liquid hermetically held in the pressure vessel 1 can be heated or cooled together by placing the pressure vessel 1 in a heating-cooling bath 3 as shown in Fig. 1. When an electrically conductive member, such as a metal tube, is used as the pressure vessel 1, the pressure vessel 1 can generate heat by applying voltage thereto. Accordingly, as shown in Fig. 2, when the pressure vessel 1 which generates heat by applying voltage thereto is used, the pressure vessel 1 is wound around an insulator 5 which is supported by tripods 4 and 4, and covered with a thermal cover 6 to keep the atmosphere within the thermal cover 6 constant. And then, this pressure vessel 1 and the liquid hermetically held in the pressure vessel 1 can be heated together by applying voltage to the pressure vessel 1 by using the electric power supplied from a power source P. In this case, it is possible to heat or cool the pressure vessel 1 in the range of temperatures higher than the melting point of the liquid hermetically held in the pressure vessel 1 and lower than the boiling point of the liquid. However, when the pressure vessel 1 is heated or cooled at temperatures in a range of several tens degrees higher or lower than the mean of the boiling and melting temperatures, the liquid flows stably without pulsation.

The liquid may be alcohols, such as methanol and ethylene glycol, ethers, such as diethyl ether and isopropyl ether, ketones, such as acetone, and ethyl methyl ketone, paraffins, such as normal hexane and isohexane, naphthenes, such as cyclohexane, aromatics, such as benzene, toluene and xylene, and water, but not limited to them. The coefficient of thermal expansion of the liquid depends on a combination with the pressure vessel 1, and therefore it does not make much difference whether the coefficient of thermal expansion of the liquid itself is high or low. In order to supply a larger amount of liquid, a liquid having higher coefficient of thermal expansion, such as methanol, diethyl ether, acetone, benzene or the like is preferred.

The heating-cooling bath 3 may be either an air bath or a liquid bath, and a sheathed heater may be used as the power source. If a heating-cooling bath utilizing a peltier device is used, heating and cooling is facilitated, and so is controlling temperature.

In an example of the liquid pump according to the present invention, a

pressure indicator 7, such as a pressure gauge, was provided at the end-opening 1b of the pressure vessel 1 of the liquid pump, as shown in Fig. 3, to measure the internal pressure of the pressure vessel 1 at various temperatures. As a result, the internal pressures were 21.6×10^5 Pa at 50 degrees Celsius, 35.3×10^5 Pa at 60 degrees Celsius, 53.1×10^5 Pa at 70 degrees Celsius and 66.6×10^5 Pa at 80 degrees Celsius. In this case, a stainless coil tube having an inner diameter of about 0.5 mm and a length of about 10 m was used as the pressure vessel 1, and ethylene glycol was used as the liquid.

In another example of the liquid pump according to the present invention, liquid chromatography was carried out as shown in Fig. 4 by attaching a joint 8 at the end-opening 1b of the liquid pump, connecting a polyether ether ketone (PEEK) resin tube 9 (0.8 ID × 450 mm) hermetically holding methanol with this joint 8, connecting an ODS column 11 (0.321 ID × 150 mm) for HPLC with an end of this PEEK tube 9 via an injection valve 10 and connecting an UV-detector 12 with this end of the ODS column 11.

In a further example according to the present invention, liquid chromatography was carried out as shown in Fig. 5 by attaching the joint 8 at the end-opening 1b of the liquid pump, connecting the PEEK tube 9 (0.8 ID × 450 mm) hermetically holding the methanol with this joint 8, connecting the ODS column 11 (0.321 ID × 150 mm) for HPLC with the end of this PEEK tube 9 via the injection valve 10, and connecting the UV-detector 12 with the end of the ODS column 11.

As a result, in both cases of Figs. 4 and 5, the UV-detector 12 indicated desired results, and an extremely small amount of liquid fed by the liquid pumps were ensured. As the pressure vessel 1 used for the liquid pump shown in Fig. 4, a stainless coil tube having an inner diameter of about 0.5 mm and a length of about 10 m was used, while a stainless coil tube having an inner diameter of about 0.8 mm and a length of about 10 m was used as the pressure vessel 1 used for the liquid pump shown in Fig. 5. As the liquid, ethylene glycol was used for the liquid pump shown in Fig. 4, and methanol was used for the liquid pump of Fig. 5.

The liquid pump according to the present invention, composed as described above, has a very simple and downsized structure with the smaller number of necessary components and provides superior cost performance.

The liquid pump according to the present invention can easily control flow of the liquid therein by heating or cooling the pressured vessel thereof.

Furthermore, the liquid pump according to the present invention is operated by only heating or cooling the pressure vessel thereof so that it does not generate unwanted noise.

Additionally, the liquid pump according to the present invention has an extremely small inner diameter of the flow channel within the pressure vessel so that an extremely small amount of the liquid can be supplied by the microliter, or even by the nanoliter.